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THE APPLICATION OF PHOTOGRAMMETRY, REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO FOSSIL RESOURCE MANAGEMENT

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Abstract—Change is one of the many challenges facing fossil resource managers today. This concept is not restricted to physical alterations affecting the resource such as erosion, visitation, vandalism or even preservation. Changes in the views of the public, policies of an administration and in the field of geospatial technology are also greatly affecting how a particular resource program or significant locality is managed. Geospatial technologies are changing and evolving at an incredible rate, resulting in not only an increase in capability, but also of complexity and expectations for the resulting product. Today, it is not uncommon to integrate a number of geospatial tools, some of which require a sophisticated knowledge of computer systems, data requirements and techniques. This is not necessarily a negative, as it sets the foundational need for partnerships with other resource specialists, academic researchers and the public across disciplines, across administrative boundaries and across agencies. Within the cadre of geospatial technologies, there are a number of tools that can greatly streamline and support land management decisions and the implementation of these decisions. These tools include utilizing imagery data sets through photogrammetry (the art and science of making measurements from photographs) and analyzing remotely sensed data. Data sets may be collected through active sensors, such as RADAR or LIDAR, or passive sensors, which collect multi- or hyper- spectral imagery. The processing of these data sets can result in detailed data files representing the terrain or geological and soil maps, to name only a few. Data sets can be combined with both coordinate and attribute data collected in the field and processed geospatially using Geographic Information Systems, a combination of computer hardware, software and data that allows information to be organized around a specific location. At paleontological localities such as the Red Gulch Dinosaur Tracksite, Twentymile Wash Dinosaur Tracksite and Picketwire Canyonlands Dinosaur Tracksite innovative geospatial technologies were tested, refined and integrated. This integrated approach not only resulted in documentation of the paleontological resource, but also supplied products used in site development, resource protection and interpretation.

INTRODUCTION

The challenges facing land managers today can be immense. Of these challenges, perhaps one of the most significant is the effects of change. Not only can a particular fossil resource be changed through time by erosion, visitation, vandalism or even preservation, but the changing views of the public and policies of an administration can drastically affect how a particular program or locality is managed. In addition, the tools used to manage fossil resources, in particular geospatial technologies, are changing and evolving at an incredible rate, which is both a blessing and a curse. Changes that have taken place over the past two years have given us the capability to quickly take a series of photographs and effectively transform them into a detailed terrain surface. The resulting surface and draped image can be posted on the World Wide Web so that the world can visit a site virtually or conduct virtual research on a specimen. Unfortunately, the incredible power available in this technological advancement comes with a price. Twenty, or even ten years ago, a "generalist" could dabble in the world of geospatial technology and be fairly confident that they had a good handle on the capabilities of a system. A project could be taken to successful conclusion using one or two techniques or software packages. As the tools have increased in capability and complexity our expectations of the resulting product have also increased. Today it is not uncommon to use a number of geospatial tools to get from point A to point B, making it more difficult for any one individual to know everything there is to know, or possibly even to complete a project to their full expectations unassisted. This is not necessarily a negative, as it sets the foundational need for teamwork and partnerships not only among spatial analysts, but with other resource specialists, academic researchers and the public across disciplines, across administrative boundaries, and across agencies.

In 1998, at the Fifth Federal Conference on Fossil Resources, presentations encouraged paleontologists and resource managers to dig in and learn everything there was to know about Geographic Information Systems (GIS). Today with the increase in technology and complexity, we recommend looking, listening, learning and reaching out to those who have geospatial expertise. Become familiar with the vast possibilities that are available in the geospatial toolbox and capitalize on them. A geospatial specialist should be included at the inception of a project, not at the end when all the data has been collected and the need for GIS analysis has arisen. These days, a cadre of highly skilled spatial analysts exists throughout our agencies although they may not exist within every office. If a geospatial specialist or team of spatial analysts are not readily accessible, request such support from management, to elevate the importance of geospatial expertise.

Past papers have provided detailed discussions of technologies that included specifics such as what type of camera to use, which software and what button to push. With the incredible rushing forward of technology, these papers, some only a few years old, are now out dated. Instead of falling into that trap for yet another paper, the following discussion will describe the available technology, what tools have worked in the past, how they can be applied to the present, thus making planning for future projects more successful.

BACKGROUND

As stewards of our natural world, we realize that all fossils are important as a natural resource for the information they provide to interpret our geologic past. As stewards of public lands, we are mandated to regulate the collection, preservation and curation of vertebrate and other fossils deemed significant. Thus, the focus of this document will be on the management of vertebrate and other significant fossil resources. Fossil resource management, in a broad sense, can be grouped into phases: resource identification, resource location and documentation and resource interpretation and management. Each of these phases of fossil resource management can benefit from the capabilities found within the geospatial toolbox. Before we discuss examples of management applications, let's fling open the lid of the geospatial toolbox and see what's inside.

World Wide Web

One of our most powerful tools, although not strictly geospatial, is information, and one of the best free sources of information is the World Wide Web. The ability to search the Web and connect to information brings the technical world to our fingertips. By simply typing a word or phrase into one of the many search engines, one can go from an overview down to very detailed information on a subject. Fast-streaming raster technology allows us to move from a digital view of our backyard to a location around the world in seconds. The descriptions of geospatial technologies that follow are intentionally brief and selective, focusing primarily on techniques that are tried and true or exhibit great potential for fossil resource management. The reader is encouraged to utilize the Web to find out more information on methods and technologies of interest. Unlike this document, the information found through the Web will continue to change and evolve over time, helping us keep current with a changing world.

Photogrammetry and Remote Sensing

Photogrammetry can be defined as the art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and other remotely sensed data (Alspaugh, 2004). Although, by definition remote sensing is a subset of photogrammetry popular use has put it into a category of its own. For many people remote sensing has become synonymous with satellite imagery imposing an unfortunate limitation on the term. Remote sensing is the act of remotely collecting data about a subject. Often this data is the signature or spectra of electromagnetic (EM) radiant energy (Lillesand, 1987). Two of the most powerful remote sensing tools have been with humankind since its inception, the human eye and brain. The eye is an extremely powerful sensing device that sends data to the brain to be processed and interpreted. Current sensor technology extends our natural capability for perceiving the visible range of the EM spectrum into very short waves, such as gamma rays and to very long waves, such as radio waves. Other phenomena, such as gravity or magnetic fields, can also be recorded. In general there are two types of sensors, active and passive, used to collect remote sensing data (Alspaugh, 2004).

Active or Detecting and Ranging Sensors

Active sensors transmit EM energy and record the reflected signals in the form of waves or data points; they include Radio Detection And Ranging (RADAR), Synthetic Aperture Radar (SAR), Interferometric Synthetic Aperture Radar (IfSAR), Light Detection And Ranging (LIDAR) and Sound Navigation And Ranging (SONAR) (Wang and Dahman, 2002). These sensors measure the length of time signals take to strike an object and be reflected back. By knowing the location of the sensor, which is provided by yet another technology, distances are transformed into elevations. The result is a digital file containing an array of points that define the surface struck by the signals (Crane et al., 2004). These files containing horizontal and vertical coordinate values are commonly referred to as digital terrain models (DTM). When evaluating the resulting DTM, two components must be considered: the spacing and the precision at which the data points are collected. To a large extent, both of these components are governed by the capabilities of the sensor; however, the object to sensor distance is also a factor (Wang and Dahman, 2002). Active sensors can be placed on a variety of platforms including satellites, airplanes, unmanned airborne vehicles and surveying tripods.

Synthetic Aperture Radar (SAR) and IfSAR, often satellite-based systems, are not limited by light conditions, thus data collection can occur at any time of day or night. The wide wavelengths of SAR and IfSAR can penetrate haze, clouds, water, snow and even sand. The DTMs resulting from these systems make a good supplement to imagery obtained by photogrammetry and are suitable for orthorectifying medium- and high-resolution satellite images (Wang and Dahman, 2002). A variety of data layers can be overlain, combined and analyzed in the GIS environment, thus new information can be generated. In addition, overlapping SAR images can be viewed in stereo and used to construct three-dimensional models (Wang and Dahman, 2002). SAR, IfSAR, and Side-Looking Airborne Radar (SLAR) have been successfully used to analyze and monitor geologically active areas such as eolian dune fields, volcanic terrain and tectonically active areas (Ford et al., 1998).

Light Detection and Ranging (LIDAR) systems emit and receive pulses from an optically-safe laser; the return provides horizontal and vertical coordinates and intensity values. The intensity values correspond to the reflectance of the material returning the signal and can greatly assist with post processing of the data. There are both aerial- and ground-based LIDAR systems. Aerial LIDAR data is often used in conjunction with aerial photography to produce digital orthophotographs (Wang and Dahman, 2002) and can be used in the production of high-resolution topography (contour intervals of one meter or greater). Ground-based LIDAR (gbLIDAR) systems, also known as laser scanning (Louden, 2003) are high-speed, high-accuracy three-dimensional data collectors with the capability to capture hundreds of points per second. Currently, these data points have a positional accuracy of +/- 6 mm (or better) when scanning at distances of less than 50 m (Matthews et al., 2001a). Ground-based laser systems are transportable, robust, field units that provide near real-time access to the data. An advantage of these systems is that measurements can be made directly from the raw three-dimensional digitized or point cloud data while in the field. This data can be utilized in a variety of software packages for the production of three-dimensional surfaces, contours and site visualization (Matthews et al., 2001a).

There are other detecting and ranging sensors that emit and receive other portions of the electromagnetic spectra, as well as other types of wave phenomenon. Several such systems use sound and include SONAR and ultra sonic guidance systems. SONAR and some specialized LIDAR systems make it possible to collect elevation beneath the surface of the water providing bathymetric data along coastlines or in shallow fluvial systems (Crane et al., 2004).

In addition to sensors that penetrate the air and water, our geospatial toolbox also contains sensors with the capability of detecting features in the ground beneath our feet. For exploration geophysics, the three main types of sensors are magnetic, gravitational and seismological. As with the active sensors discussed above, the platform can vary from satellite- to ground-based (Short, 2006). Data collected from these sensors has given us an incredible wealth of information that has increased our understanding of geological processes on a global scale. However, it is the ground-based use of these techniques that prove most directly beneficial to fossil resource management. As with the active remote sensing technologies described above, there are a wide variety of techniques and sensors that record and measure different types of information. Although there are most certainly many sensors that could prove useful for fossil resource management, the discussion below will feature three techniques with proven results and future possibilities.

Ground-penetrating radar (GPR) is a geophysical method that involves the transmission of high frequency radar pulses from a surface antenna into the ground. The elapsed time that it takes for the energy transmission to be reflected back to the surface is measured (Conyers, 2004). The near-surface features that reflect the signal can include buried materials such as fossil specimens or changes in sediments and soils. When antennas are moved along grided transects, many thousands of radar reflections are measured and recorded, thereby producing a three-dimensional picture of subsurface soil, sediment and material changes (Conyers, 2004). The power of this technology is the detection of change below the surface; unfortunately, there are several factors that can adversely affect this capability. These factors include the presence of significant amounts of clay minerals, high moisture content and materials of similar reflectance (Gillette, 1994; Conyers, 2004).

Geophysical diffraction tomography (GDT) utilizes acoustic energy to create a seismic profile. Data is collected from a string of hydrophones (water-coupled microphones) in a water-filled borehole; a seismic gun is moved along a sequence of lines radiating out from each borehole. The acoustic waves are recorded and after processing a sequence of vertical seismic profiles result (Witten et al., 1992). The velocities at which the acoustic waves pass through the ground are affected by the composition of the rock layers. Thus, variations in rock density, moisture, fault lines and other variables can affect acoustic wave transmission through the subsurface (Witten et al., 1992; Gillette, 1994).

Radiological survey instruments (RSI) detect ionizing radiation, i.e., gamma radiation, emitted by elements such as uranium and vanadium (Jones et al., 1998). When materials containing these elements are present in the subsurface they are often detectable at the surface. The RSI collects these ions and sends them to an instrument that measures the ions. Once measured, a response is generated and recorded. By utilizing a predetermined grid system a survey can be conducted and a spatial representation of the radiation is produced. For this technique to be effective it is necessary to have materials with levels of radiation higher then their surroundings (Gillette, 1994; Jones et al., 1998).

Passive or Raster Sensors

Passive sensors record reflected or emitted EM energy. These sensors rely on the external illumination from a light source (such as the sun). Some passive sensors can pick up thermal emissions, thus are most effectively used during times of low sun illumination such as sunset or at night (Alspaugh, 2004; Short, 2006). There is a large cadre of passive sensors; most detect the EM energy that falls within the visible part of the spectrum. However, there are a growing number of sensors that operate in the upper end of the visible and well into the thermal wavelengths. The resulting image data commonly falls within the categories of panchromatic, multispectral, hyperspectral and ultraspectral (Alspaugh, 2004; Short, 2006).

Panchromatic images are collected by single-band sensors that capture wavelengths in the visible or near infrared (IR) part of the EM spectrum (Lillesand, 1987). An excellent archival resource, especially for foreign countries, is imagery taken from the declassified CORONA satellite missions (Alspaugh, 2004). The resolution of these black and white images varies, but is often around 5 m. This data can be useful in parts of the world where aerial photography or even maps of adequate scale are not available.

Multispectral sensors commonly collect from four to eight EM bands at intervals through the visible and near IR part of the spectra (Short, 2006). Currently, there are 30 optical civil land-imaging satellites and four privately funded systems in orbits that cover the United States (Stoney, 2006). When evaluating imagery data for its utility, a very important consideration is the resolution or ground sample distance (GSD). The current orbiting sensors can be divided into two major resolution groups: high-resolution systems (0.5-1.8 m) and mid-resolution systems (2.0-39 m). The area an image can cover is called the swath width; high-resolution swaths are in the 8 to 28 km range and mid-resolution swaths are generally between 70 and 185 km (Stoney, 2006). Due to the large variety of image collection capability represented by these systems, it is very difficult to discuss them individually. An excellent resource for information on these satellite sensor systems is available on the Web and is provided by the American Society for Photogrammetry and Remote Sensing (Stoney, 2006). Commercial satellite imagery can be very current, very expensive and often comes with licensing restrictions that controls who the imagery can be shared with. However, much of the commercial imagery is also available archivally making it a more affordable data source. Of worthy mention is imagery from Landsat 7. This imagery has proven to be an excellent tool for mapping geology and vegetation. The U.S. Geological Survey (USGS), Earth Resources Observation Systems (EROS) data center, provides an archive and source for obtaining current and older Landsat data, as well as other types of imagery (Stoney, 2006).

Hyperspectral sensors collect EM radiation centered over the visible, extending into the thermal and infrared, and can record this spectrum in over 200 bands. As with other passive sensors, the GSD is related to the height of the platform on which the sensor is housed. Satellite-based hyperspectral sensors produce resolutions from 15 to 90 m (Short, 2006), while much higher resolutions can be obtained when sensors are housed on airplanes. Hyperspectral imagery can offer a much greater spectral resolution resulting in an almost continuous spectral signature. As with multispectral imagery, the analysis' power comes with the ability to combine various bands and classify the results. However, with hyperspectral imagery, there are a much greater number of possible band combinations many of which are extremely sensitive to geological features (Short, 2006). To help interpret these data there are spectral libraries that link reflectance and wavelength to the materials that produce them. Also, as with multispectral sensors, it is important to incorporate ground truthing into the data collection and analysis process. Portable ground based spectrometers can be taken into the field and used concurrently with aerial data acquisition. When the spectra of features are collected on the ground, a supervised classification of the imagery can occur providing a higher probability of success (Short, 2006).

Although currently in the developmental stage, there is an emerging group of sensors referred to as Ultrasprectral. These sensors are being developed by the military to target very narrow bands of the EM spectra, particularly radioactive wavelengths (Jasani, 1997). Although developed to detect signals emitted from weaponry and other nuclear sources, in the future there could be potential applications to geology and paleontology.

Photogrammetry

As with the term remote sensing, popular use has synonymized photogrammetry with the measurement or processing of aerial photography. Photogrammetry has traditionally utilized commercially acquired, large-format aerial photography. The photogrammetric processing of aerial photography has generated extremely valuable products such as topographic maps, digital orthophoto maps and digital elevation models series produced by the USGS. But with new advances in technology there is more to photogrammetry than the predominant 1:24,000 scale products.

Photogrammetry can be used to measure, document or monitor almost anything that is visible within a photograph and can be divided into categories based on the distance of the camera from the subject. Aerial photogrammetry typically refers to oblique or vertical images acquired from distances that are greater than 300 m (Breithaupt, et al., 2004b). The distance of the camera from the subject in commercial aerial photography is a limitation imposed by the Federal Aviation Administration. When aerial photography is flown at a height of 305 m (1000 ft) above mean terrain with a 153 mm focal length lens, the result is photography at 1:2000 scale. The smallest object that can be detected is 5 cm. Most large format aerial photography is acquired through commercial contractors and is available in hard copy or digital formats. Generally, aerial acquisition is designed and planned according to the specifications needed to generate a particular product over a specified area (Breithaupt et al., 2004b). Larger area acquisitions (whole counties or states) are conducted by federal and local governments. Many land management agencies, including the Bureau of Land Management (BLM), maintain aerial archives that contain historical aerial photography over the lands they manage. Information on these archives is available through agency websites. The National Agriculture Imagery Program (NAIP) is managed by the U.S. Department of Agriculture Farm Services Agency (FSA) and covers agricultural lands in the United States. Other governmental agencies are partnering with FSA to produce statewide coverage of current orthorectified natural-color, one, two and ten meter imagery.

Close-range (also referred to as terrestrial or ground-based) photogrammetry (CRP) has an object-to camera distance of less than 300 m. A variety of cameras and platforms may be used to obtain the photographic images to be used in CRP processing, including cameras housed in unmanned airborne vehicles, suspended below helium-filled blimps and mounted on tripods (Breithaupt et al., 2004b). It is proposed that the definition of close-range be restricted to between 50 and 300 m, and that object-to-camera distances of less than 50 m be referred to as extreme close-range photogrammetry. Theoretically there is no limit to the resolution that can be achieved from CRP images.

The same requirements that exist for a successful aerial photogrammetric project—camera calibration, control coordinates for camera orientation and stereo-photo pairs—are also required by CRP (Matthews and Breithaupt, 2001; Breithaupt et al., 2004b). Conventional survey techniques, such as Global Positioning Systems (GPS), may be adequate for close-range projects where the ground sample distance (GSD) is larger than the accuracies achievable by GPS methods. In extreme CPR, the GSD is often very small (less than one millimeter) requiring a ground control survey method of similar accuracy. So far, survey instruments that can achieve that level of precision are not economical for use in a field setting, thereby requiring a more affordable hybrid method to be developed (Matthews et al., 2004a,b).

Three-dimensional measuring and modeling software (3DMM) is a hybrid process that can be integrated into the traditional photogrammetric process that meets the requirement for high-level accuracy in a nontraditional way. Sophisticated camera calibration is the key to the 3DMM software that can be performed on any camera that can be set to a repeatable focal length (for example, at infinity). The software can use many photographs taken from many different perspectives in addition to stereo pairs of photographs. The 3DMM software has the ability to mark circular objects at the subpixel level greatly improving project accuracy. In addition to simple circles, the software supports coded targets to aid in the task of identifying the same point on multiple photographs (Matthews et al., 2004a,b). Coded targets are essentially circular bar codes with a center circle and arcs of varying lengths surrounding it.

The tools required for field collection of photogrammetric data using the hybrid method are a digital camera and fairly inexpensive software. This process is very robust and can be applied to a large variety of resource issues and used by persons with a wide range of technical expertise. Once photographs have been acquired and oriented with 3DMM software, the resulting camera orientations can be imported directly into a softcopy photogrammetric workstation because the cumbersome processes of control point collection and aerotriangulation have been circumvented. Although traditional photogrammetric control is not required to orient the stereo photographs, it can be utilized to tie the microtopographic data into a real-world coordinate system (Matthews et al., in press). Microtopographic data is generated in the photogrammetric workstation through a process known as automated digital terrain extraction, commonly referred to as autocorrelation or digital image matching. It is a process in which sophisticated software matches pixels (picture elements) with unique spectral and geospatial values within one digital image to similarly valued pixels in the adjacent image of the stereo pair.

The result of the data generated using extreme CPR and softcopy photogrammetric analysis yields a dense grid of x, y and z coordinate points that can be accurate to +/-0.5 mm depending on project scale. Photographs taken from high resolution consumer digital cameras (six megapixels or greater) utilizing the hybrid method can easily produce digital three-dimensional surfaces and detailed microtopographic contour maps for areas as large as 5 m^2. Larger areas can also benefit from this type of documentation; however, camera platforms other than handheld or tripod may be required to achieve the required photo orientations. Depending on size of the area and height above the subject positional accuracies may be reduced.

Both the traditional aerial and hybrid photogrammetric processes enables the interpretation of imagery and the collection of data necessary to produce reliable maps that give land managers confidence that their decisions are defensible. The data for the photogrammetric process customarily take the form of topography (terrain or land surface) or planimetry (such as streams, transportation routes, vegetation and cultural information). However, all raw photographs have inherent distortions predominantly from effects of camera tilt and relief displacement whereby features at higher elevations are displaced away from the center of the photo (Alspaugh, 2004). To eliminate these distortions, the ground geometry is re-created as it would appear from directly above each point in the photo. This is accomplished by applying a process called differential rectification to each pixel in the image. However, an orthophoto is a photograph that has already been corrected to eliminate distortions and can be utilized as a map. Orthophotos, as discussed previously, can be produced from many types of raster data, from 30 m satellite imagery to one-millimeter extreme close-range photographs (Breithaupt et al., 2004b). The geospatially corrected imagery products are an integral component in the next tool we will take from our geospatial toolbox, Geographic Information Systems, or GIS.

Geographic Information Systems

The concept of using two-dimensional lines and symbols to convey information about our three-dimensional world dates back to the time when man first started to communicate. Presenting information about our natural world has always been an important part of our existence—from etching hunting locations or techniques on a rock wall or preserving building stone locations scribed on papyrus. As the tools used to locate ourselves on the earth have become more sophisticated, our maps have become more accurate, easier to produce, and easier to update. Tools such as GIS not only allow us to make better maps faster, but provide us with real-time access to data. The most significant part of GIS is the analysis, specifically, the ability to generate new information by manipulating preexisting data. Powerful expert systems allow multiple data sets to be modeled and integrated proving very useful in resource management problem solving. This capability changes our concept of geospatial data, how it is viewed, processed, analyzed and utilized.

A GIS is a combination of computer hardware, software and data that allows information to be organized around a specific location. This technology integrates database functions and statistical analysis with map-like visualization and geographic analysis allowing for the integration, visualization, management, analysis, interpretation and presentation of a variety of geological and paleontological data in ways never before possible. All types of data collected about a specimen, a locality, a rock unit, a state or any other type of geographic container can be integrated using GIS. Complex relationships can now be documented and evaluated in ways that could not be done previously using any other type of analysis, thereby increasing the value of that data. Data that is brought into the GIS can be acquired through a wide variety of methods, including orthoimagery, field collection and geospatial data via the World Wide Web.

Geospatial Clearing Houses

Geospatial clearing houses provide a digital portal to free or low cost geospatial data. These data gateways provide digital versions of USGS 7.5 minute quadrangle maps, digital orthophoto quads, vector files (depicting such features as transportation, vegetation and hydrography), digital terrain models (DTM) and even geological and soils maps. Understanding the parameters and quality of data is fundamental to reliable analysis. Consideration must be given to manipulating data of varied quality or resolutions. The Federal Geographic Data Committee (FGDC) is an interagency committee that promotes the development, use, sharing and dissemination of geospatial data and imagery. To this end the FGDC has developed a standard for metadata. A metadata file contains data about the geospatial data including coordinate system information, how the geospatial data was captured and produced and attributes of the data file they accompany.

Coordinate Collection

The acquisition of field data has been incredibly streamlined by the use of GPS. GPS technology has changed rapidly over the past few years thereby making accurate receivers very affordable. In addition, innovations such as the data logger and personal digital assistant (PDA) allow tabular data and images to be linked to GPS points. These data can be brought directly into the GIS. Currently, many consumer-grade receivers are accurate to five meters, although a number of factors can affect accuracy for better or worse. A GPS unit receives signals from satellites. When signals are available from four or more satellites, a position can be determined mathematically. The accuracy depends upon the geometry of the tracked satellites, how strong the signals are and how long the unit can communicate with the satellites. The result is a position that can be captured and then transformed into a variety of coordinate systems such as geographic (Latitude and Longitude) or projected (Universal Transverse Mercator (UTM) or State Plane) coordinate systems (Chapman et al., 2002).

Differential GPS (DGPS) can achieve accuracies that are good to the centimeter level. To achieve this level of accuracy at least two GPS receivers are needed; one remains stationary (the radio base station) while other units rove collecting position measurements for unknown points. The stationary receiver is set up on a survey point of known accuracy, such as a benchmark and uses the known position to calculate the timing to the satellite (Matthews et al., in press). The travel time of the GPS signal is compared with that collected from the rover unit, a correction factor is computed and later processing applies this correction factor to the rover position measurements resulting highly accurate geographic coordinate locations. The National Aeronautics and Space Administration, U.S. Coast Guard and other entities maintain highly accurate reference networks, such as High Accuracy Reference Network (HARN) that have reference points throughout the world. These reference points can be used with DGPS and when using a single receiver. Computer software takes the input from the GPS receiver and, when on a computer linked to the Web, goes out to specific sites and downloads very up-to-date information about these reference points. The corrections from these points are then incorporated in the post processing. Positional accuracies using a single GPS receiver and post processing using the reference networks can be good to 0.5-1 m depending on the type of GPS unit used (Chapman et al., 2002; Matthews et al., in press). High positional accuracies can also be achieved by subscribing to broadcast services such as ProXRS, (OmniStar). These services mimic the radio base station component of DGPS.

It is important to keep in mind that there is more to a particular GPS collector than positional accuracy. User interface and the ability to store and handle attributes along with the location can vary. Both the collection of field data and the carrying of attribute data into the field are desirable for scientific work. As with GPS, data collected from more traditional survey equipment such as electronic distance meters (EDM), total stations and similar systems can be imported into a GIS (Breithaupt et al., 2004b). Robotic total stations and computerized EDMs record coordinate and attribute data much the same way as the data loggers and PDAs. Conversion software is available that supports the processing and import of these systems into a GIS format. The resulting accuracy can rival DGPS; however, these survey devices provide location data in a user-defined coordinate system. In order to tie data to a real world system, known benchmarks or locations documented through the use of GPS must be used. In addition, basic string-line grid systems can be accurately and efficiently converted into a digital system when care is taken in the accuracy of their construction and supporting measurements made on elevation and orientation of elements.

Imagery Analysis

In some cases, valuable field data can be collected without even leaving the office. The source of these data comes from the interpretation of imagery. As discussed previously, a wealth of geological, paleontological and resource management information can be collected from a variety of imagery types. By inspecting and interpreting imagery, time spent conducting field prospecting can be greatly streamlined. Aerial imagery can be used to focus on particular areas that meet the necessary criterion and avoiding those that do not. Thus, the same amount of time may be spent in the field, but that time is maximized. Ground-truthing is still necessary when it comes to finding fossil resources.

Data Synthesis

Once the field data has been collected, the process of combining the various components—aerial and close-range photography, survey and GPS coordinates, field observations and measurements and information taken from other maps or DTMs—begins. Images can be registered to the coordinate data, three-dimensional data sets can be processed and evaluated and tabular (or spreadsheet) data can all be integrated into the GIS environment. The ability to link tabular data to graphic displays makes GIS a very powerful tool. Vector (point, line and polygon) data all have associated tables (Breithaupt et al., 2004b; Matthews et al., in press). These tables or databases can contain an abundance of information, such as year collected, species, bone orientation or length of track (Chapman et al., 2002). Unique identifying fields (e.g. specimen number) can link several tables, which can all be queried as one, allowing different categories of data about the same subject to be kept in discrete databases. With a common identifying field, databases, regardless of origin, may be "attached" and combined for analysis. This can be helpful when databases (perhaps housed in universities) can be separated from precise location information and used for statistical analysis. An exciting component of GIS is the ability to link the database to graphic locations and symbolizing these locations based on different attributes found in the database. Thus, relationships between paleontological elements become more obvious and perhaps, things that appeared to be related in the field may actually be random or random observations may fall into a pattern (Chapman et al., 2002; Breithaupt et al., 2004b).

Not only can a GIS aid in analysis through the use of a number of tools, but the advanced graphical capabilities support virtual three-dimensional reconstruction of a resource. One such application could be the construction of a virtual quarry map, representing fossils and other elements found within a site. The virtual map could be used not only as a primary research tool but, for interpretive and educational applications as well; individuals could take virtual tours and select individual components, bringing up more detailed data including high resolution images and three-dimensional models. These views can be digitally rotated and analyzed at an infinite number of angles to help piece together the prehistory of the site (Chapman et al., 2002; Breithaupt et al., 2004b).

EXAMPLES

As with technology, fossil resource management is very complex, often changing and always demanding. Within this paleontology, great potential for conflicts exist and often many options must be explored in order to reach an acceptable outcome. A few selected projects have been chosen for illustration of where some of the tools in the geospatial toolbox have been applied to fossil management issues. In looking at past projects, it is helpful to keep in mind the goals of fossil resource management. Generally stated, these goals are to identify areas were fossil resources exist, support scientific study through documentation, preserve the resource through collection and curation and keep the resource safe when it is *in situ*.

The following projects were chosen for illustration because of space limitations or because they represent first hand experience of the author. They are by no means are the only ones that have utilized geospatial technology and there are most certainly other projects that are excellent illustrations of how best to use GIS, photogrammetry or remote sensing. Remember, these projects they are already dated because the technology has evolved, been refined and can be applied more economically and more quickly. But, for these very reasons they deserve consideration for future projects.

Finding the Resource

Geographic Information Systems (GIS) can be an incredible tool for reconnaissance-level resource management. Several different digital data layers such as geology, vegetation, soil type, topography and ownership can all be viewed and analyzed as described above. This type of analysis allows examination of such questions as, "Where can I find exposures of the Morrison Formation with sparse vegetation, on BLM land?" Utilizing digital geologic maps and other supporting digital data, geologic formations and their geospatial expressions can be grouped or classified according to the likelihood that they would contain vertebrate fossils. The level of management awareness or sensitivity with which a formation should be regarded can then be attributed within the GIS (Bryant and Matthews, 1998; DeBlieux et al., 2003; Kirkland et al., 2006).

A limitation to this type of analysis is, unfortunately, data that is incomplete or too generalized. Often geological maps of the appropriate scale are not available, or when available, do not completely cover the area of interest. However, metadata can be of great assistance in determining when and how data can be used in a particular project. Fortunately, imagery analysis using natural color aerial photography and multispectral and hyperspectral sensors can provide refined geologic and lithologic information. An example of this is lithofacies mapping of the exposed Jurassic section in the Bighorn Basin of north-central Wyoming. This mapping was conducted using remote sensing data, specifically Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data sets (Strasen, 2004). Principal component analysis, band ratios, minimum noise fraction and spectral sharpening techniques were performed on the visible and near infrared (VNIR) and shortwave infrared (SWIR). Data calibration was accomplished by acquiring field spectral readings of a wide variety of lithofacies at known locations with a portable spectroradiometer. Results of the analyses exhibit subtle and dramatic spectral variations that correlate to known lithologic changes in the field. These changes were not evident from simply analyzing high-resolution digital air photos. By extrapolating ASTER data from known lithofacies to areas with no field data, promising outcrops were identified. UTM coordinates were extracted from the ASTER data and located in the field using GPS for navigation. One of the benefits of this analysis was the location of an oolitic limestone facies in the field not detected by other remote sensing methods. These promising results demonstrate the utility of combining and analyzing imagery data sets as an important tool in geologic mapping (Strasen, 2004).

By combining GIS analysis with imagery classification processing and aerial photograph interpretation, on the ground paleontological surveys can be greatly streamlined and focused. By adding GPS and data loggers, positional and attribute data about resources can be entered in the field. The navigational, or waypoint, capability of most GPS units can also provide great assistance in relocating the resource for further investigations. Digital data on fossil locations can be more easily integrated into State databases. A Statewide, comprehensive digital database for the State of Utah is being developed through a cooperative project between the BLM and the Utah Geological Survey. This database is being inputted into a spreadsheet format and includes data on locality, geology and repository (DeBlieux et al., 2003; Kirkland et al., 2006). This data can also be utilized in developing and refining paleontological sensitivity maps (Bryant and Matthews, 1998; DeBlieux et al, 2003; Kirkland et al., 2006). By utilizing the capabilities of relational databases, information about exact fossil locations can be kept separate from pertinent paleontological information. This allows for proprietary information to remain secure while information important to researchers or the general public can be made available in a more generalized format.

Resource Documentation and Interpretation

Once the existence of a fossil resource is established, decisions on how best to approach documenting and preserving that resource must be made. In the case of skeletal remains, will fossils be extracted or as with a tracksite, will the resource be open and interpreted for public benefit? In either case, documentation is essential to the scientific understanding and future management of the resource.

Determining the extent of a proposed quarry or amount of overburden to be removed before the resource is exposed can significantly influence how an excavation proceeds. Tools such as geophysical diffraction tomography (Witten et al., 1992; Gillette, 1994) and radiological survey instruments (Gillette, 1994; Jones et al., 1998) can be effective for planning where to dig. These systems can provide the information on the sub-surface position of material and other features. Geophysical diffraction tomography (GDT) can create a probable three-dimensional sub-surface map showing extent, thus providing information about the volume of sediment to be removed.

Once skeletal materials are exposed, current technology can be an enormous help in mapping the fossils and recording important contextual data. A great deal of information is available from the context of the fossils within the sediments, including distribution of other flora and faunal elements and changes in lithology that may be present. These data can indicate the environment that produced the outcrop and even significant bits about the biology of the dinosaurs found there. Electronic Distance Measurement devices (EDMs) and other advanced surveying equipment can help document the spatial location of fossils within a quarry with sub-centimeter accuracy. For elongate fossils, the position of each end is recorded to provide orientation data (Chapman et al., 2002). In addition, close-range photogrammetry of a quarry site taken from the surface or through the use of a blimp or other unmanned airborne vehicles can not only provide detailed measurements and coordinate data, but a visual record of materials surrounding the bones (Breithaupt et al., 2004b).

Ground-based LIDAR (gbLIDAR) has been widely utilized to document historic structures and archeological sites (Louden, 2003), but its use in the documentation of paleontological resources is somewhat limited (Breithaupt et al., 2004b; Matthews et al., 2004a,b). gbLIDAR is an excellent means to capture a wealth of three-dimensional data on a subject in a very short time, but there is a high expense associated with this technology. However, considering the product, it may prove to be an affordable means of data collection. Photo-realistic virtual outcrops have been created by combining gbLIDAR with digital imagery to document geological features. These spatially and geometrically precise models of real-world surface exposures are being utilized to visualize, analyze and interpret geologic features such as bedding planes, faults and three-dimensional fracture networks and other sedimentary structures (McCaffrey et al., 2005; Clegg et al., 2005). A feature of LIDAR that could prove very beneficial to skeletal documentation is the intensity value that is returned along with the coordinate value. By utilizing this information, variations in surface textures between bone and matrix may be detected. Not only can a virtual outcrop be produced, but also virtual reconstruction of quarry sites and skeletons, thus allowing the subject to be viewed from a variety of perspectives. Three-dimensional laser imaging technology shows great promise for the documentation, study, interpretation and archiving of paleontological resource data (Breithaupt et al., 2004a; Matthews et al., 2004a,b).

Tracking Dinosaurs

The evidence of the interaction of a prehistoric animal with its environment is preserved in the fossil footprint record. Detailed aerial and close-range photogrammetry along with digital spatial data utilized in GIS, provide excellent tools for documenting tracksites. Paleontological sites on public land in Colorado, Wyoming, and Utah have been extensively documented using a synthesis of close-range photogrammetry and established ichnological field methods resulting in a very precise approach for the measuring, recording and evaluating of fossil tracks (Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004b).

The Red Gulch Dinosaur Tracksite (RGDT) lies on the eastern flank of northern Wyoming's Bighorn Basin and is located approximately 22 km southwest of Shell, Wyoming. The initial discovery of tracks at the RGDT in 1997 was in a "dry wash" exposed along the Red Gulch/Alkali National Backcountry Byway. The floor of the dry wash is composed of an oolitic limestone member of the Middle Jurassic Sundance Formation (Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004a,b). Established ichnological field methods were utilized to locate and document the very subtle tracks on the limestone surface. GPS data collecting, precision surveying and photogrammetry were utilized to produce a geospatial framework. A comprehensive database of information was constructed from the field documentation and the geospatial framework.

Extensive photographic documentation of the tracksite included 30 m resolution satellite imagery, standard format aerial photography, 35 mm photos taken from tripod heights of 2-10 m, a remote-controlled airplane, an Ultralight aircraft, a blimp and close-range photogrammetric images (0.3 mm resolution) of a single track (Figs. 1-3). As a result of this combined approach to documentation over 1,000 dinosaur tracks were identified, described, geospatially located and photographed at the RGDT (Fig. 4)(Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004a,b). Based on the analysis of this synthesized data, interpretations about the animals that were present in northern Wyoming during the Middle Jurassic may be made.

The limestone surface at the RGDT contains tridactyl pes impressions of small- to medium-sized carnivorous dinosaurs estimated to weigh between 10 and 230 kg. Statistical analysis of individual track measurements indicated that only one taxa of dinosaur was present at RGDT (Sizemore, 2000; Breithaupt et al., 2001; Breithaupt et al., 2004a). These tracks are arranged into at least 125 discrete trackways (ranging from 2 to 45 steps). Based on a statistical analysis of the trackways, pace angulations (ranging from 158 to 180 degrees) represented those typical theropod dinosaurs (Wright and Breithaupt, 2002). Calculated trackway speeds ranged from 3.6 km/h (2.2 mph) to 10.8 km/h (6.5 mph), indicating that the majority of dinosaurs were walking (Breithaupt et al., 2001, 2004a, in press). Further spatial analysis revealed that trackway arrangements are present. One such arrangement consists of straight, nearly parallel groups of trackways with very similar orientation. Within these groupings, consistent distances were maintained between trackways and no evidence of overprinting of one track on top of another was observed. Another arrangement consisted of individual trackways exhibiting a more sinuous, intertwining path, which overprints other tracks, representing separate intervals of track generation (Breithaupt et al., 2004a, in press).

Through the study of the RGDT exciting interpretations on the behavioral complexities of a Middle Jurassic theropod community can be made. Evidence of adjacent trackways groups with no overprinting suggests gregarious behavior in this community. Data for the Red Gulch Dinosaur Track Site supports the interpretation of small, mixed-age packs of theropod dinosaurs (ranging from yearling to adult) traveling together, possibly as a family group (Breithaupt et al., 2004a, in press). The presence of an oolitic limestone indicates a peritidal zone, rich with diverse marine biota. It is possible that the dinosaurs that left their footprints may have been journeying to a food source or foraging as they traversed the ancient tidal flat (Breithaupt et al., 2004a, in press).

FIGURE 1. Extensive photographic documentation of the Red Gulch Dinosaur Tracksite utilized a variety of camera platforms included tripod heights of 2-10 m, a remote-controlled airplane, an Ultralight aircraft and a blimp.

The Twentymile Wash Dinosaur Tracksite (TWDT) is located approximately 25 km southeast of the town of Escalante, Utah in BLM's Grand Staircase-Escalante National Monument. The site was discovered in 1998 (Foster et al., 2000; Hamblin and Foster, 2000) during a paleontological survey. Exposed along the top of a bench of Middle Jurassic Entrada Sandstone is a five-meter thick, track-bearing horizon. Within this horizon, tracks and trackways are exposed at multiple levels representing numerous episodes of track formation and preservation. Tridactyl tracks (ranging in length from 15 to 45 cm) of theropod dinosaurs and unique sauropod tracks and traces were noted (Foster et al., 2000; Hamblin and Foster, 2000).

Based on experiences gained from the documentation of the RGDT, project planning began with an archival search. Raster data found in the search included USGS digital raster graphic and orthophoto quadrangle maps. Natural color aerial photography taken in 1995 at a 1:24,000 scale was obtained from the BLM Aerial Photography Archive housed at the National Science and Technology Center in Denver, Colorado. Based on this imagery, it was decided to obtain three additional scales of photography—commercial aerial photography at a scale of 1:3000, close-range aerial blimp photography at a scale of 1:70 and extreme close-range photographs at a scale of 1:30.

High-accuracy DGPS ground control coordinates, collected in conjunction with the blimp photography, were utilized to georectify the digital versions of the 1:3000 scale and blimp photography (Breithaupt

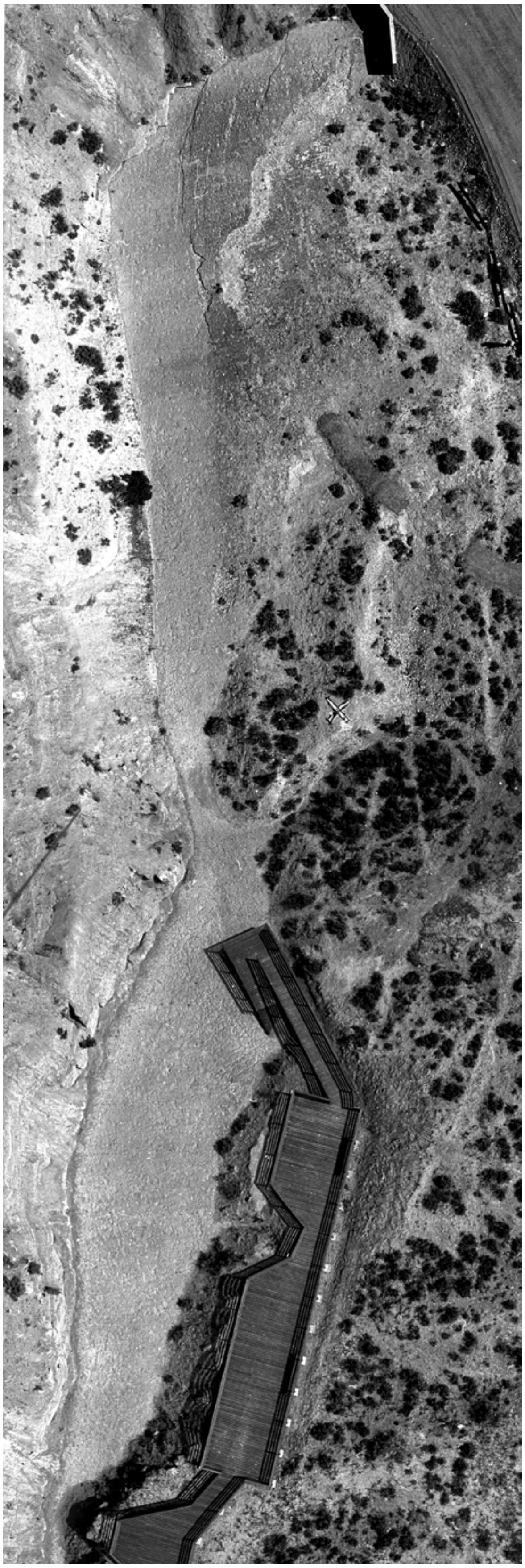

FIGURE 2. Low-level aerial image of the Red Gulch Dinosaur Tracksite taken from the blimp.

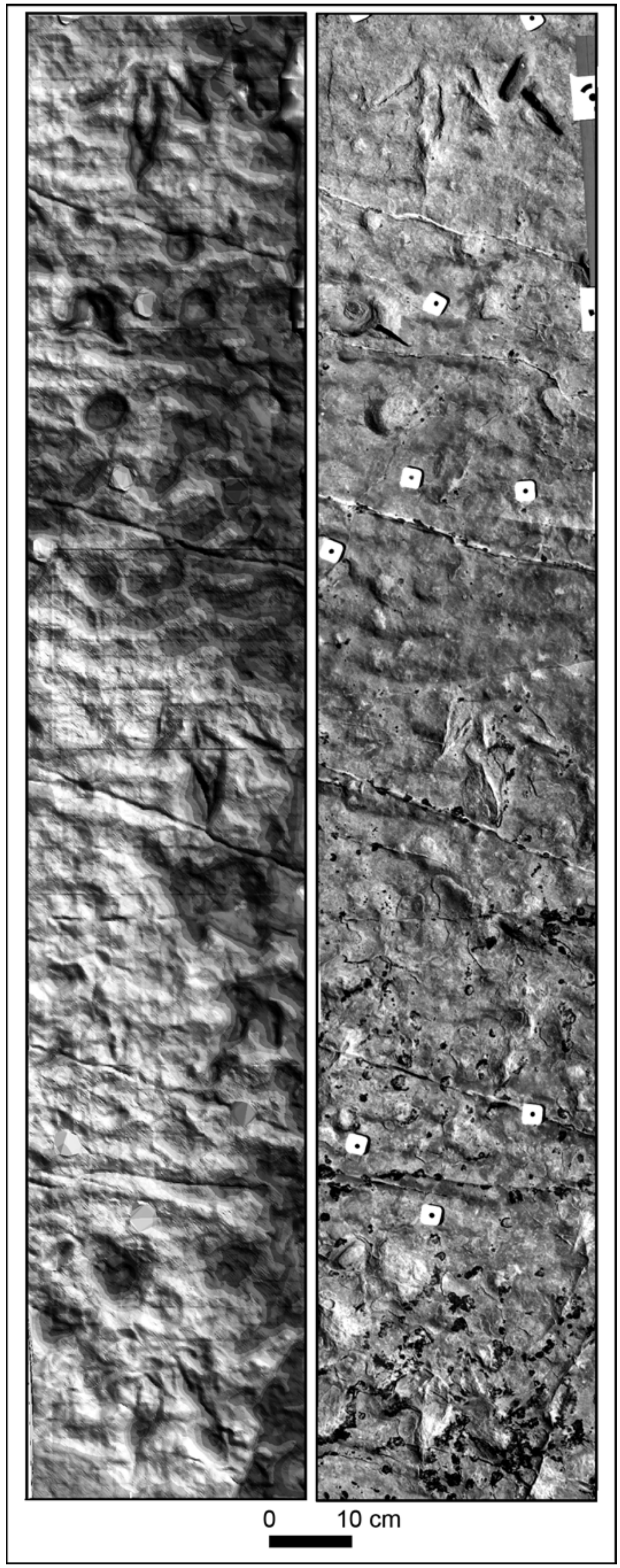

FIGURE 3. Digital terrain model (on left) with 2 mm post point spacing, color banding represents changes in elevation. Digital orthophotograph (on right) of three steps in a dinosaur trackway at the RGDT.

et al., 2004b; Matthews et al., 2005a,b, in press). As with RGDT project, automated terrain extraction from the commercial aerial photography was conducted in the softcopy photogrammetric workstation, resulting in a digital terrain model. The softcopy photogrammetry system in turn utilized the DTM to remove distortions in the imagery caused by changes in terrain. The result is digital orthophotographs for both scales of photography producing an integrated data set of imagery allowing a user to zoom from an overall perspective of the site to a photograph of an individual track (Matthews et al., in press).

Complete stereoscopic coverage of the main track-bearing layer was obtained using the blimp. These photographs were viewed in the softcopy photogrammetric workstation. The stereo models were inspected and a polygon outline was digitized around each track. A field inspection of the digital track database was conducted and on the ground measurements were made of selected tracks and trackways. GIS analysis of the database supports sequentially numbering of individual tracks and the grouping of tracks into trackways. Statistical analysis of trackway geometry (including foot length and width ratios, pace angulations, stride lengths and straddle widths) was conducted in the GIS environment (Breithaupt et al., 2004b; Matthews et al., 2005a,b, in press).

When initially reported in 2000, the number of tracks recorded at the TWDT was around 300 (Foster et al., 2000; Hamblin and Foster, 2000). As a result of the in-depth geospatial documentation of the site 964 dinosaur tracks and associated traces have been identified and documented in three-dimensional space (Fig. 5). The great majority of the tracks at TWDT exhibit significant morphologic variation. Within a single trackway, morphology can vary in as few as three steps from distinct tridactyl footprints (with evidence of digital pads and claw impressions) to oval concentric (or ovoid) rings representing deep underprints. Variations in pace angulations, ranging from 135 degrees to 170 degrees or higher, are also exhibited.

The horizontally-bedded sandstone units of the "upper sandy member" of the Middle Jurassic Entrada Sandstone can be informally grouped into stratigraphic horizons. Within these horizons there is evidence of changes in track to trackway ratios, track way orientation and pace angulation. Also present are horizons of multi-directional trample

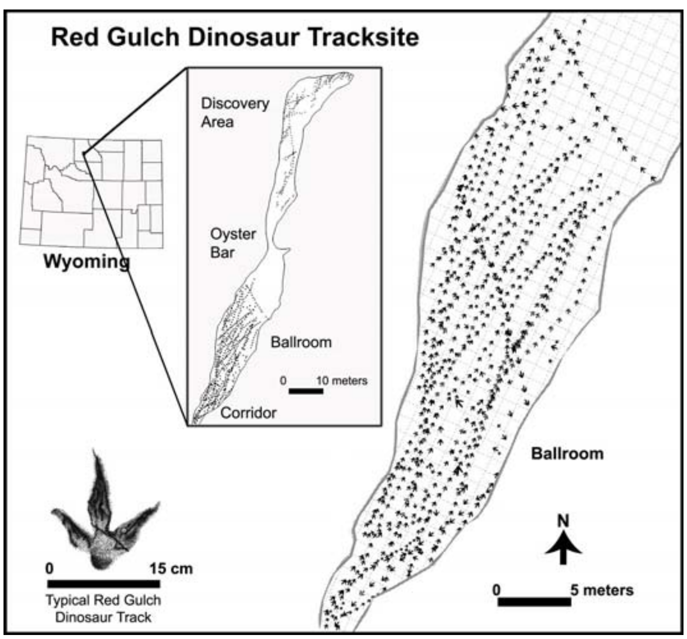

FIGURE 4. A map, produced from surveyed point locations, of tracks in the "Ballroom" at the Red Gulch Dinosaur Tracksite (RGDT). Track icons are scaled to relative sizes based on measurements made during documentation and input into the GIS database. Overall view of the main track bearing area at RGDT (upper left inset). Illustration of a "typical" RGDT dinosaur track (lower left inset).

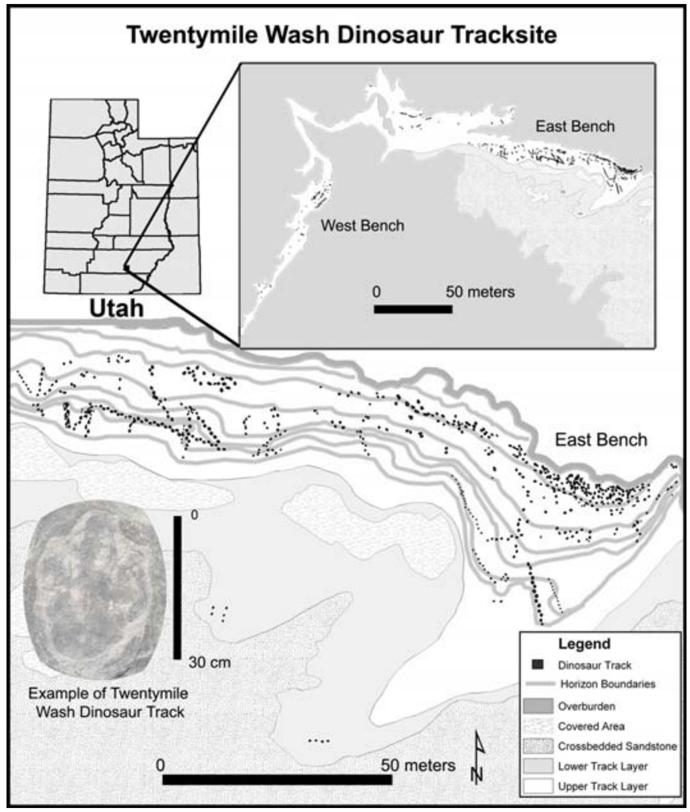

FIGURE 5. Map of the main track-bearing layer at the Twentymile Wash Dinosaur Tracksite (TWDT). Track locations were compiled photogrammetrically from low-level aerial images taken from the blimp. Gray lines represent boundaries between stratigraphic horizons. Representative TWDT footprint (lower left inset). Overall view of the TWDT (upper right inset).

zones (with as many as 90 randomly placed tracks in an 80 m^2 area) (Matthews et al., 2005a,b, in press). The Entrada Sandstone of southern Utah was deposited in eolian dune fields on the margins of a large intracontinental seaway that stretched from Idaho and Wyoming into southern Utah. Coastal fluctuations occurred as tidal flats, lacustrine and fluvial systems influenced the area (Foster et al., 2000). Stratigraphic horizons at TWDT appear to contain variations in trackway orientation, current direction and possibly faunal assemblage. Interpretations based on the analysis of the geospatial database support paleobehavorial responses, exhibited by populations of theropod dinosaurs, to fluctuating environments. These responses can be traced over time through the stratigraphic horizons and may possibly represent seasonal migrations, feeding or faunal variations through time. These types of changes can reflect ecosystem changes occurring on a broader scale in the terrestrial systems of the Middle Jurassic (Matthews et al., 2005a,b, in press).

Resource Management

The process of fossil resources management is an iterative one that relies on a number of factors. One fundamental factor is obtaining the information necessary to formulate options and develop management strategies. Optimally, these management strategies would be based on complete scientific evaluation and documentation of a resource. As mentioned previously, in many cases complete data may not exist or may be too costly to obtain. In addition, the pressures of multiple-use and desired future condition may be in conflict resulting in a streamlined decision-making process.

For such cases, GIS may be of great assistance, especially in areas of high paleontological significance. By defining the paleontological sensitivity of geological formations, significant areas can be distinguished. Sensitivity levels are based on the type and distribution of fossils. Examples of sensitivity categories include areas where fossils are absent, rare or present. In addition, areas with significant, very sensitive and extremely sensitive (such as world famous localities) can be delineated (Fig. 6) (DeBlieux et al., 2003; Kirkland et al., 2006). This can be valuable to land managers because it provides assistance in decisions to open or restrict areas from surface disturbing or other potentially destructive activities. Once delineated, certain activities may be precluded in or redirected to particular areas or restricted to specific areas in order to protect the resource and support multi-use. One facet of fossil resource management that most likely will not change is the potential impact of public opinion and the importance of including the public in the management process.

In February of 1999, the Wyoming BLM opened a 30-day comment period for review of the environmental assessment and proposal to designate the Red Gulch Dinosaur Tracksite as an Area of Critical Environmental Concern (ACEC). Based on the resulting public input, a Decision Record and Finding of No Significant Impact (FONSI) were approved in July of that year. A recreation plan was developed based on the FONSI. Both the FONSI and ACEC designation are available for download from the BLM Worland Office Web page. Among the goals of the plan were to provide a safe visit to the site, allow scientific study to continue, prevent damage to the tracks and implement signage explaining the significance of the site. Planned improvements to the site included the construction of trails, installation of facilities (including shelters, picnic tables and walkways), addition of signs and improvement of the roadway. The graphical products created during the documentation and research stage of the project were used extensively to implement the goals of the recreation plan. Road improvements and the location of facilities utilized the topographic and planimetric maps made of the area surrounding the dry wash. The ramp that provides foot and wheel chair access to the track surface in the dry wash was located and designed based on the track locations found by the researchers and digitally documented in the GIS. Informational signs installed along the trail leading from the parking lot to the track surface utilized imagery and maps to both orient and interpret the site to visitors. The amount of documentation of the dry wash allowed for a base line to be established of the condition of the resource prior to development. Future studies at the site can be compared to the baseline in order to assess the impacts of visitation and other factors to the site.

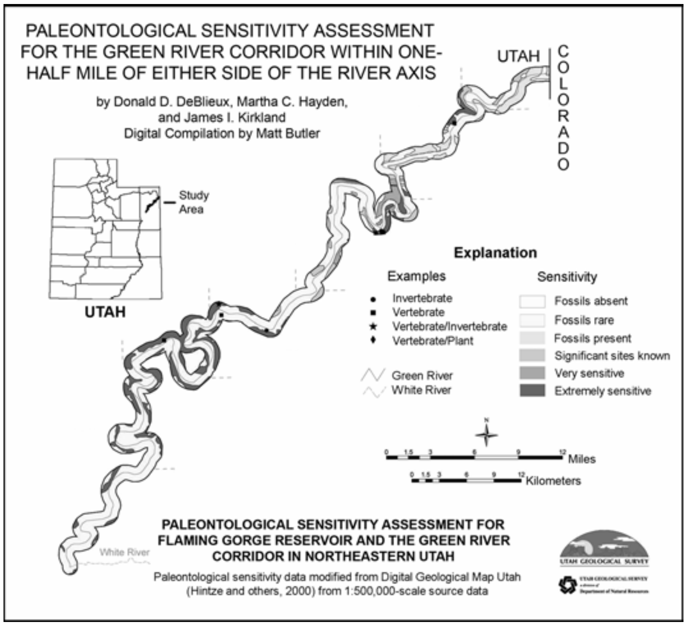

FIGURE 6. Paleontological sensitivity assessment map for the Green River corridor within one half mile on either side of the river (DeBlieux et al., unpubl. report for U.S. Bureau of Reclamation, 2002).

In addition to the impacts of the human population on fossil resources, it is also necessary to keep these resources safe from such natural phenomena as erosion. An excellent example of fossil resource *in situ* preservation is an ongoing effort of the U.S. Department of Agriculture Forest Service. The Picketwire Canyonlands Dinosaur Tracksite is located along the Purgatoire River on the Comanche National Grassland in Las Animas County, Colorado. At this site a one-quarter mile limestone exposure of the Late Jurassic Morrison Formation contains over 1300 tracks. The site contains large sauropod tracks as well as a variety of sizes of theropod and ornithopod footprints (Lockley et al., 1999) arranged into approximately 100 different trackways. The tracksite is exposed today due to the erosive effects of the Purgatoire River; unfortunately, that same force is also eroding the soft shale that lies beneath the limestone layer that forms the tracksite. When the river erodes this shale, the resulting undercutting of the tracklayer occurs causing it to fall into the river. Photography at a variety of scales (1:3000, 1:600 and close-range) was used to document the site. Black and white, 1:1300 scale, aerial photography was taken in 1994. Ground control was established and a topographic map with a 0.25 m contour interval was compiled. Aerial photography was taken again in 1998 and the riverbank was remapped. In 2001, photography at a scale of 1:650 and 1:600 was obtained using a blimp (Fig. 7) (Matthews et al., 2001b; Wright and Breithaupt, 2002; Breithaupt et al., 2004b). This photography allows further monitoring of the effects of erosion on the site and is being used to compile a very detailed track map. The Forest Service has taken steps to protect the tracksite and ensure its long-term preservation by installing erosion control structures. These structures are constructed from eroded blocks of limestone and help deflect the river's current energy away from the tracksite. In addition, these structures cause sediment build up against the tracksite further protecting it (B.A. Schumacher, personal commun., 2006) (Fig. 8).

Herein lays one of the conundrums of fossil resource management. On one hand, sedimentation is deliberately encouraged to cover and protect the resource; while on the other hand, studies continue to quantify its subsurface extent. This situation underscores the need to have the best data in order to make the soundest decisions. One such tool that can be used to help define the subsurface extent of the resource is Ground Penetrating RADAR (GPR). In the summer of 2000 and 2001, GPR was tested at the Picketwire Canyonlands Dinosaur Tracksite with

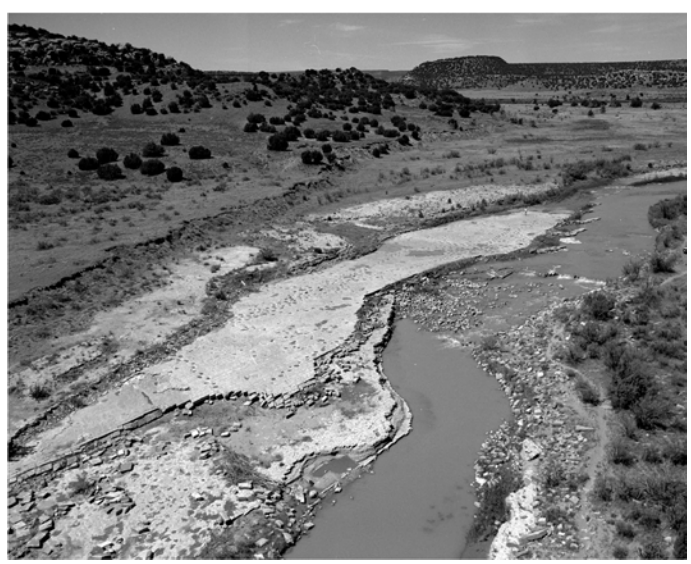

FIGURE 7. Oblique aerial view of the Picketwire Canyonlands Dinosaur Tracksite (PCDT) taken from the blimp.

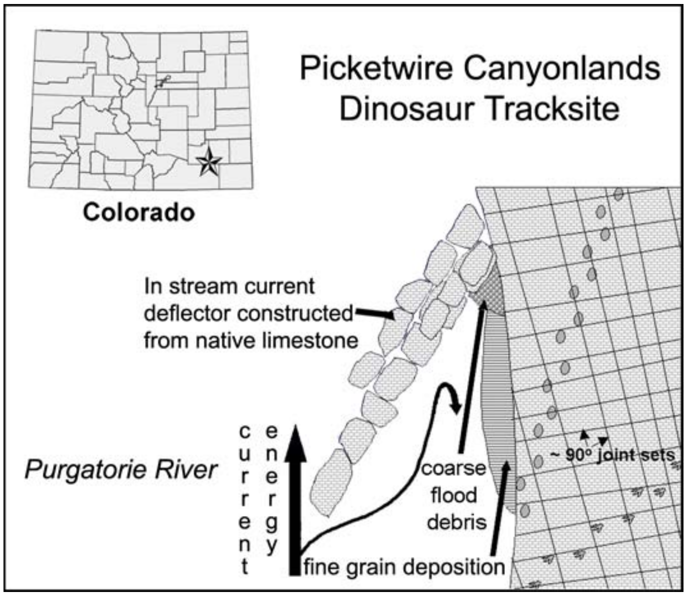

FIGURE 8. Design plan for erosion control structures to protect the PCDT limestone layer (Image courtesy USDA, Forest Service).

very promising results (L.B. Conyers, personal commun., 2006). Data profiles were collected through the overburden, showing very distinctly that tracks were present (Fig. 9A). Based on the post processing of the data, a spatial distribution of the detected depressions in the limestone layer was produced (Fig. 9B). The result is perplexing—while many of the features are undoubtedly tracks, other surface features were also detected. A variety of factors can adversely affect the return of the GPR signal, including clay and water content. This technology can be very beneficial in distinguishing between where tracks do and do not exist in the subsurface (L.B. Conyers, personal commun., 2006), thus making it a potentially valuable tool, especially at sites adjacent to planned construction.

CONCLUSION

Advances in technology are occurring at an astonishing rate providing resource managers with more efficient and cost effective methods for data collection and analysis. However, to more fully utilize developing geospatial capabilities, sophisticated users of these technologies may be needed, thus setting the foundation for teamwork and partnerships. These partnerships can be forged across disciplines, across agencies and may include resource managers and the public. By combining individuals with a variety of skills, experiences and knowledge, working toward a common goal, often more can be accomplished.

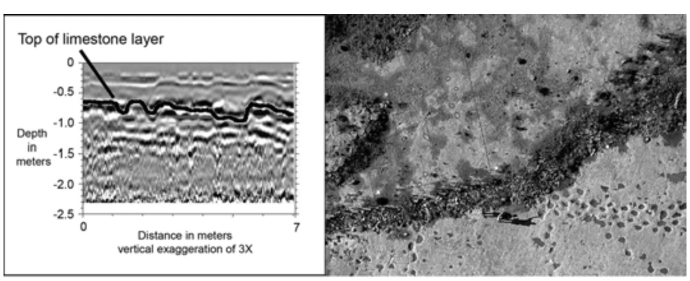

FIGURE 9. **A**, Ground Penetrating Radar (GPR) profile collected at the Picketwire Canyonlands Dinosaur Tracksite (PCDT). The GPR signal penetrated the overburden, showing distinct track impressions. **B,** Post processed GPR data depicting the spatial distribution of depressions in the limestone track layer PCDT. Back ground image was taken using the blimp (Images courtesy L.B. Conyers).

The same may be said for geospatial technologies. Techniques, such as photogrammetry, ground-based LIDAR and Ground Penetrating RADAR can be combined to produce a virtual three-dimensional recreation of a paleontological resource. These virtual resources can be utilized for research, to analyze the effects of certain management practices and for interpretation to the public. Acquiring and archiving quality digital data so that it is portable and accessible is a priority that must not be ignored.

Technologies that may have been dismissed in the past due to cost, or which were considered inaccessible due to the need for technical expertise, should be given new consideration. As a technology evolves it often becomes more transportable, cost effective and user-friendly. Even as existing technologies are being refined and applied, a whole new set of advancements are looming over the horizon for fossil resource management. These include the use of wireless data transfer, rapid prototyping, websites with fast data streaming capabilities and single-portable files that contain embedded layer and coordinate information (3-D.pdf), to mention only a few. Although incredibly exciting, these "new" technologies bring up questions of accessibility to data as well as security risks to the computer system that house them which must be assessed and addressed in an enlightened manner.

With the burgeoning of geospatial technology, the process of defining project goals, developing data standards, defining successful outcomes and developing an achievable implementation plan is vital. Just because a geospatial technology or dataset is available, inexpensive or looks impressive does not mean that it will always work for every application. It is important to do a thorough investigation of the technologies to ensure that the data being acquired supports the result to be achieved, the World Wide Web can play a principal part in this process. Caution should also be taken to budget sufficient resources, not only for data acquisition, but also to analyze, interpret and maintain geospatial data sets.

Among the challenges that face the fossil resource manager are not only the changes seen in the advancement of technology and in the policies that govern decisions, but also the sheer volume of fossil resources contained on public lands in the western United States. The number of scientifically significant fossil localities is too numerous to list or reference and new localities are being found on a regular basis. These sites are often on public lands managed by state or government agencies (e.g., Bureau of Land Management, Forest Service, Bureau of Reclamation and the National Park Service). Often these sites must be managed with the goal of multiple-use and desired future condition in mind. Tools contained in the geospatial toolbox can be of vital assistance to identify areas were fossil resources exist, support scientific study through documentation, preserve the resource through collection and curation and keep the resource safe when it remains *in situ*.

At localities such as Red Gulch Dinosaur Tracksite, Twentymile Wash Dinosaur Tracksite and Picketwire Canyonlands Dinosaur Tracksite, innovative geospatial technologies were tested, refined and integrated (Breithaupt et al., 2004b). Such integrated approaches not only resulted in documentation of the paleontological resource, but also supplied graphic products used in site development, resource protection and interpretation. The data collected at these sites established a baseline of digital data ensuring vital scientific information is largely preserved should these resources be damaged or lost as the result of illegal collection, vandalism, erosion or human interaction. Future generations could still have access to these resources through digital virtual reconstructions served over the Web or as solid models constructed with detailed terrain data. As our society changes and the demands of an ever-increasing population draw heavily from our public lands, it is important to remember that many of these same challenges faced the prehistoric populations of the western United States. The behavioral responses exhibited by extinct animals to global and regional changes in climate, disease, sea level, deforestation and resource depletion could give vital insight into the future history of our world and how the management decisions made today will influence that future.

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